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1 Gbit/s COHERENT OPTICAL COMMUNICATION SYSTEM USING A 1 W OPTICAL POWER AMPLIFIER

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An experimental 1 Gbit/s, coherent optical communication system that uses a 1 W semiconductor optical power amplifier is reported. The system is intended for use in free-space crosslink applications, operates at a wavelength of 972 nm and uses a frequency-shift-key (FSK) modulated semiconductor laser master oscillator, heterodyne detection receiver, and delay-line discriminator demodulator. Communication link sensitivities of 30 detected photons per bit at a 10^{-6} bit error rate have been obtained. This link performance can support gigabit per second rates across geosynchronous distances.

Introduction: The performance achievable in a high-speed free-space optical communication link is typically limited by the combination of telescope aperture, receiver sensitivity and transmitter power. These systems usually operate in a power starved regime where any increase in available transmitter power can be used to either increase the system bit rate or decrease the required aperture with a corresponding reduction in system weight and launch cost. Additional system characteristics that help obtain a low overall system weight are a high electrical-to-optical power conversion efficiency and a simple laser system. These last two characteristics are best met by semiconductor devices.

We report an entirely semiconductor based, 1 Gbit/s, 1 W coherent optical communication system whose performance is suitable for free-space crosslink applications [1]. Sensitivities of 30 detected photons per bit at a 10^{-6} bit error rate (BER) and 65 detected photons per bit at a 10^{-9} BER have been obtained. This is the highest power coherent optical communication system using all semiconductor sources reported to date.

System description: A simplified block diagram of the system is shown in Fig. 1. The transmitter was constructed in a master oscillator power amplifier (MOPA) configuration. This approach, which has previously been used to advantage in injection locking experiments [2], allows the use of a comparatively low power master laser to meet the modulation, linewidth, and frequency stability requirements while a high power amplifier is used to provide optical power gain.

The master oscillator was a distributed Bragg reflector (DBR) laser from Spectra Diode Laboratories (SDL) which operated in a single spatial mode and single spectral mode [3]. Direct FSK modulation was obtained by passing the output of a 1 Gbit/s pseudorandom-data generator through an FM equalisation circuit that reduced pattern dependent effects and partially compensated for the high frequency rolloff in the laser. This predistorted signal was then amplified, combined with the DC bias current of the laser in a commercial bias T and used to drive the laser. The FSK modulated output

from the master oscillator was passed through beam shaping optics and an optical isolator before it was routed to the input facet of the power amplifier.

The amplifier was a strained layer, tapered travelling wave amplifier [4]. The tapered geometry allows high output powers and efficient energy extraction while maintaining the spatial beam quality of the master. The taper angle of approximately 6° accommodates the diffraction of the input beam, spreading the amplified signal over a larger area as it gains in power. This reduces the tendency for the high-power propagating beam to self-focus. Cavity spoiling elements are also included in the amplifier design to prevent lasing even at high gain. The 2 mm long device had an input aperture of 10 μ m and an output aperture of 200 μ m.

The measured far-field intensity profile of the amplifier output measured along the axis parallel to the junction is shown in Fig. 2. The amplifier was biased at a current

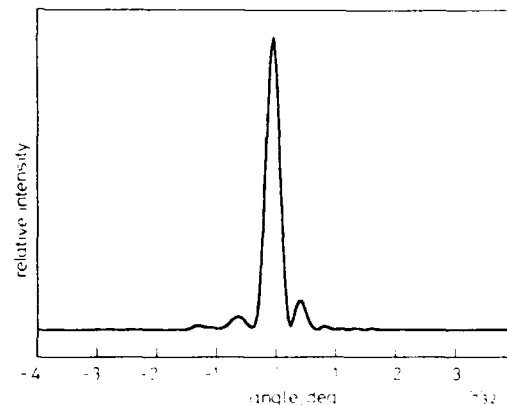


Fig. 2 Amplifier far-field spectrum

Total power = 1.24 W, P_{in} = 18 mW, lobe power = 1.05 W, λ = 972 nm

and was operated with a heatsink temperature of 21°C. The amount of master oscillator power incident on the input coupling lens of the amplifier was 18 mW. A total of 1.2 W of optical output were obtained with 1.0 W contained within the nearly-diffraction-limited main lobe.

The amplifier output was collimated using spherical and cylindrical optics. To simulate the loss due to free-space propagation, the majority of the output power was sent to a beam dump and to beam diagnostics. A small portion was picked off, further reduced in intensity by a computer-controlled variable optical attenuator and then routed to the heterodyne receiver.

The heterodyne receiver consisted of a second SDL DBR laser operated as a local oscillator, a 5 GHz bandwidth balanced mixer receiver front end, and 3 GHz bandwidth limiter delay-line discriminator demodulator. An intermediate-frequency (IF) centre frequency of 1.5 GHz and an FSK tone spacing of 1200 MHz were used. The measured IF linewidth was 4 MHz. The frequency tracking loop was implemented using filtered low-frequency information split off from the discriminator output that was fed back to the LO laser current controller. The remaining discriminator output was then filtered, amplified, and used as an input signal to the bit-error-rate tester. Clock signals were obtained directly from the data source.

Communication results: The measured communication performance of this system is shown in Fig. 3. The data were taken using a $2^{10} - 1$ pseudorandom bit sequence. This was the longest sequence that the bias-T of the laser could support without excessive degradation. The open data points correspond to the measured performance of the system without the optical power amplifier. The closed points were obtained with the power amplifier in place and a measured main lobe power of 1.0 W. Sensitivities of 30 detected photons per bit at a 10^{-6} BER and 65 detected photons per bit at a 10^{-9} BER were obtained. Over the majority of the measured signal levels the two measured curves are virtually identical and there are no

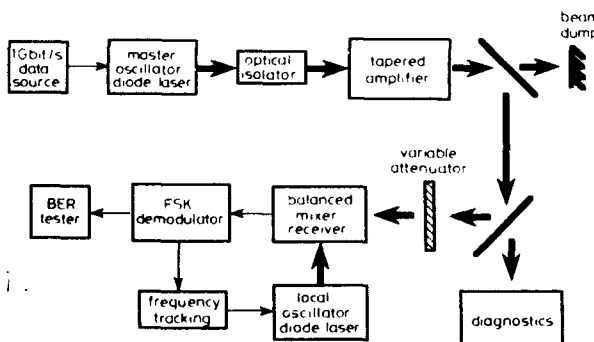


Fig. 1 System block diagram

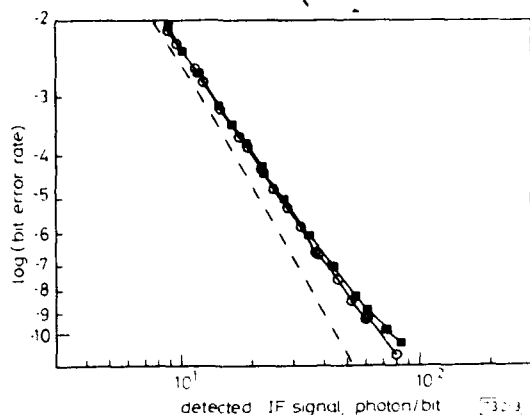


Fig. 3 Measured bit error rates

- BER without amplifier
 - BER with amplifier
 - zero linewidth theory
- 1 Gbit/s, $2^{10} - 1$ PRBS

observable degradations introduced by the optical power amplifier. The slight degradation in performance observed with the amplified system at error rates near 10^{-10} is due to residual optical feedback between the amplifier and the master oscillator laser and would be reduced by improving the optical isolation. The measured performance is also compared to the zero linewidth theory for orthogonal binary FSK. The amplified system operates within approximately 2.7 dB of the ideal orthogonal binary FSK quantum limit of 40 photons per bit at 10^{-9} BER.

Conclusion. We have reported a 1 Gbit/s, 1 W, free-space, coherent optical communication system based entirely on semiconductor devices. There was no appreciable degradation due to the use of an MOPA transmitter configuration. Receiver sensitivities and transmitter power are sufficient to support gigabit per second crosslinks at geosynchronous distances with 20-30 cm telescope apertures.

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